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Autonomous Control Modes and Optimized Path Guidance for Shipboard Landing in High Sea States

Progress Report (CDRL A001)

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Section I: Project Summary

1. Overview of Project

This project is performed under the Office of Naval Research program on Basic and Applied Research in Sea-Based Aviation (ONR BAA12-SN-0028). This project addresses the Sea Based Aviation (SBA) initiative in Advanced Handling Qualities for Rotorcraft.

Landing a rotorcraft on a moving ship deck and under the influence of the unsteady ship airwake is extremely challenging. In high sea states, gusty conditions, and a degraded visual environment, workload during the landing task begins to approach the limits of a human pilot's capability. It is a similarly demanding task for shipboard launch and recovery of a VTOL UAV. There is a clear need for additional levels of stability and control augmentation and, ultimately, fully autonomous landing (possibly with manual pilot control as a back-up mode for piloted flight). There is also a clear need for advanced flight controls to expand the operational conditions in which safe landings for both manned and unmanned rotorcraft can be performed. For piloted rotorcraft, the current piloting strategies do not even make use of the available couplers and autopilot systems during landing operations. One of the reasons is that, as the deck pitches and rolls in high sea states, the pilot must maneuver aggressively to perform a station-keeping task over the landing spot. The required maneuvering can easily saturate an autopilot that uses a rate limited trim system. For fly-by-wire aircraft, there is evidence that the pilot would simply over-compensate and negate the effectiveness of a translation rate command/position hold control mode. In addition, the pilots can easily over-torque the rotorcraft, especially if they attempt to match the vertical motion of the deck.

This project seeks to develop advanced control law frameworks and design methodologies to provide autonomous landing (or, alternatively, a high level of control augmentation for pilot-in-the-loop landings). The design framework will focus on some of the most critical components of autonomous landing control laws with the objective of improving safety and expanding the operational capability of manned and unmanned rotorcraft. The key components include approach path planning that allows for a maneuvering ship, high performance station-keeping and gust rejection over a landing deck in high winds/sea states, and deck motion feedback algorithms to allow for improved tracking of the desired landing position and timing of final descent.

2. Activities this period

Task 1 - Plant and Disturbance Model

On May 12, the Office of Naval Research and the Naval Surface Warfare Center released the initial set of standard deck motion time histories under the Systematic Characterization of the Naval Environment (SCONE) program. The motion data was for a Generic Surface Combatant similar to a DDG class ship. The data include "low", "medium", and "high" deck motion cases for both roll-dominated and heave-dominated conditions. In order to align our analyses with these standard deck motion cases, considerable effort was performed at ART to integrate the SCONE ship motion data into the FLIGHTLAB simulations of the medium utility helicopter. As of this reporting period, two SCONE deck motion cases (for low and medium heave dominated motion) were incorporated into our simulations. FLIGHTLAB drives ship motion referenced at the CG while the SCONE data only defines the flight deck motion. Since FLIGHTLAB uses the same reference coordinate system for both ship airwake and ship motion, ART needed to develop transformations to the original SCONE data in order to integrate it within FLIGHTLAB reference frame. The efforts were also needed to integrate and test the SONCE data with ship deck motion forecasting scheme in order to create a full simulation model for control design and testing support. Because of these efforts, development and release of the UAV and heavy class helicopter

simulation models (which was planned for this quarter) were delayed.

Note that the SCONE "low" and "medium" heave-dominated motion cases, which were the main cases studied in this reporting period, exhibit relatively large dynamic motion. Table 1 summarizes the motion for the medium case used in our studies. The +/-13 ft and 12 ft/sec maximum heave displacement and velocity are of specific interest. This case presents a significant challenge to the automatic landing problem.

	Displacement		*Rate (deg/sec or ft/sec)*	
DOF	***RMS***	***Max/Min***	***RMS***	***Max/Min***
Roll	0.94°	3.5°/-4.1°	0.66	3.3 /-2.8
Pitch	0.91°	3.7°/-3.4°	0.89	3.9 / -3.3
Yaw	0.21°	1.2°/-0.7°	0.15	0.49 / -0.58
Sway	2.1 ft	4.3 /-13 ft	0.88	3.3 / -3.7
Heave	2.5 ft	25 /-3.5 ft	2.4	11.7 / -10.8

Table 1 Ship Motion Properties for SCONE Medium Heave-Dominated Case #2

Task 4 – Dynamic Inversion Control Design

The DI control law was extensively tested and refined over the past reporting period for approaches, station-keeping over the moving deck, and ship landings. The controller was tested using the medium utility helicopter with the latest SCONE deck motion data, focusing on medium amplitude / heave dominated deck motion. The results of these analyses (and details of the control design) were reported in our European Rotorcraft Forum paper that was submitted in mid-July 2015.

Figures 1 and 2 show sample results of the control law analyses. In these simulations, the helicopter is commanded to hold position over the center of the flight deck and track the rolling and heaving motion of the deck. Figure 1 shows the x, y, z tracking error, while Figure 2 shows the actuator control activity. In these figures, the roll axis command filter natural frequency parameter was varied between 2, 3, and 4 rad/sec. This effectively governs the roll axis bandwidth. Since the outer loop control lateral position commands pass through the roll-axis command filter, this parameter has significant effect on the tracking performance. As shown below, the tracking error reduces with higher bandwidth. However, there are diminishing returns between 3 and 4 rad/sec. The cost of higher bandwidth is higher effective gain with the outer loop lateral position control. This likely results in lower stability margins (we are currently analyzing these margins). It is interesting to note, however, the actuator control travel (shown in Figure 2) is not significantly affected by the higher bandwidth. The result of this test was to select a natural frequency of 3 rad/sec for the roll-axis command filter frequency, as there was diminishing improvement in lateral tracking above this bandwidth.

It is interesting to note that in these tests the vertical axis altitude tracking was very tight with the DI control law (even with the large heave motion in the SCONE data, the tracking error is quite small). Typically, lateral axis tracking over the rolling flight deck was found to be more critical. However, as we begin to consider higher gross weight conditions and torque limits, the vertical axis might become more challenging.

The controller has been tested for numerous approaches in support of the AIAA paper published in June 2015, and the ERF paper submitted in July 2015. The controller is sufficiently flexible to generate approach paths with

different azimuths, glideslopes, initial velocities, and deceleration rates (the parameters that govern these properties are discussed in more detail under Task 6). Figure 3 shows sample approach paths for a 0 degree and 45 degree azimuth. Figure 4 shows the effect of an aggressive approach path strategy. This figure shows the altitude profile for two stern approaches, one with range to peak deceleration, r_{pd} = 300 ft, and the other r_{pd} = 200 ft. The short deceleration range results in a rapid deceleration and degrades the controller performance. This is seen by the large undershoot in the altitude.

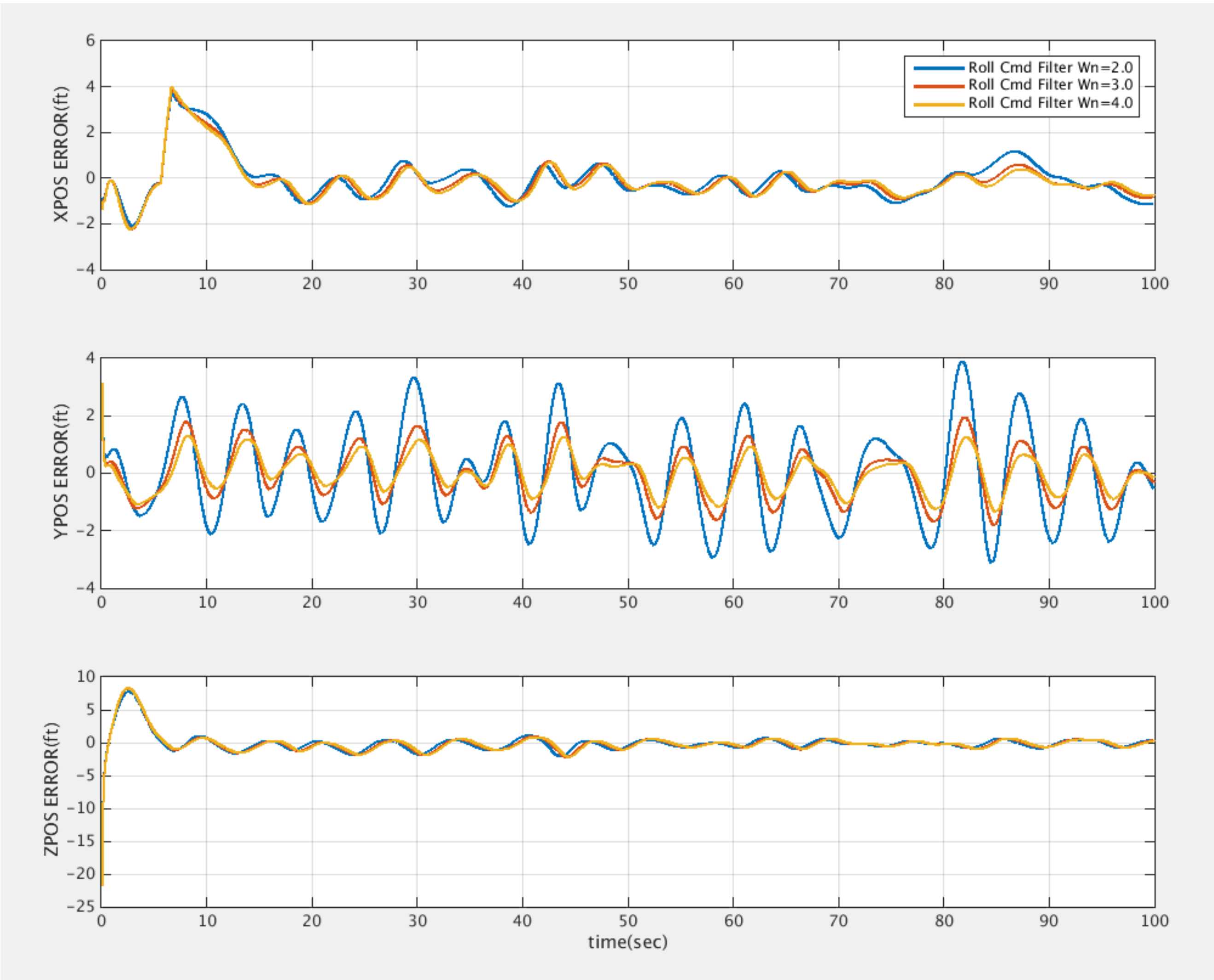


Figure 1 Tracking error when station-keeping over moving deck with various roll command filter frequencies

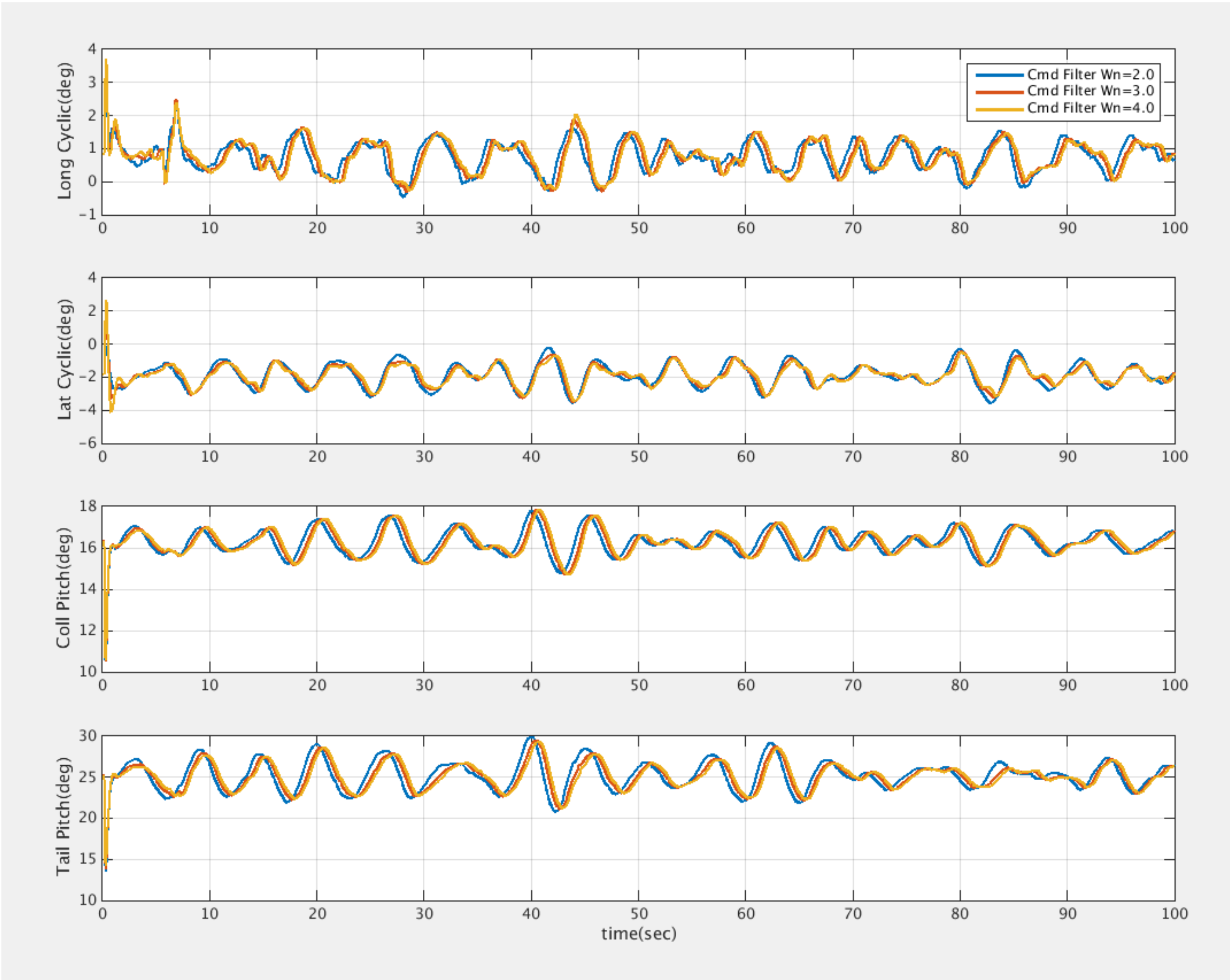


Figure 2 Actuator activity when station-keeping over moving deck with various roll command filter frequencies

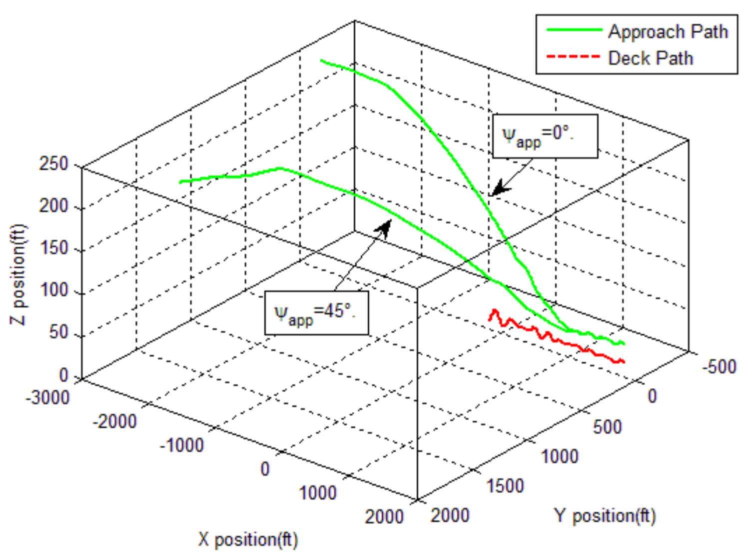


Figure 3 Approach trajectory from 0° and 45° azimuth

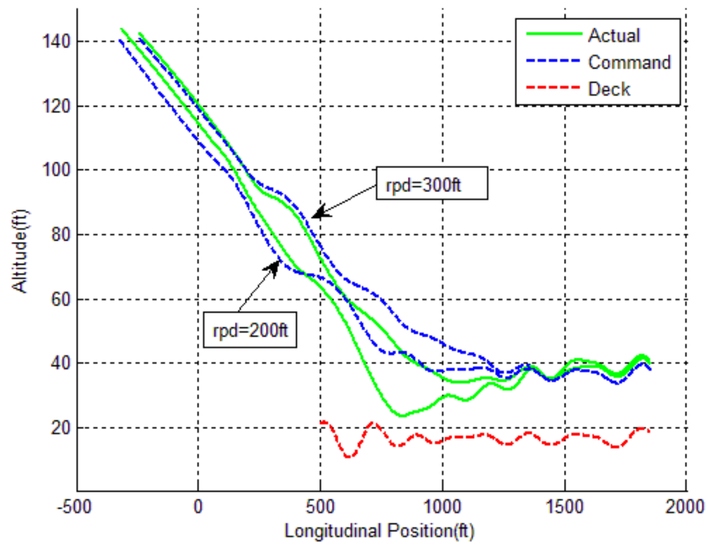


Figure 4 - Final altitude tracking during approach ($\psi_{app} = 0°$, r_{pd}= 200 ft and r_{pd}= 300 ft)

During this reporting period, the performance of the control law was also tested for ship landings. Two approaches were investigated for the autonomous landing phase. The first method is a simple approach that attempts to follow the measured deck motion during the entire landing phase. This is considered the baseline case, and does not use the deck motion prediction algorithms. However, simulation results showed that this approach had surprisingly good performance. The second approach is to time the landing so that the helicopter approaches the deck smoothly but terminates with an acceptable relative velocity. To achieve this timing, a deck motion prediction algorithm with an optimal control scheme is proposed. This approach is considered more desirable as it avoids unnecessary maneuvering during the descent while tracking large dynamic motions of the deck.

Landing results were first generated using the simple descent maneuver while tracking the center of the deck in the x and y axes. During descent, the helicopter maintains a steady *relative* descent rate, tracking the deck heave motion throughout. The simulations start at a stationary hover 20 ft over the flight deck, and then initialize a descent after 10 seconds. The simulation is completed when all three landing gear are in contact with the deck (at which point collective is lowered to its minimum setting). Figure 5 shows a sample trajectory. The red vertical lines indicate time of deck contact (first the tail gear, followed by the left and right gear shortly afterwards). The results also show the helicopter climbs and descends three cycles during the process, as it maintains a steady relative descent rate of 1.5 ft/sec. Thirty randomized cases were performed to analyze the performance of this control scheme (starting the simulation at different random points in the ship motion time history). The performance was surprisingly good, with the helicopter landing within 2 ft of the landing spot in every case. A more challenging metric is the rate of descent and relative lateral velocity at which each landing gear impacts the deck at touchdown. Results are shown in the left half of Figure 6. The maximum sink rate of the three landing gear was less than 2 ft/sec in 63% of the cases. In no case did the relative velocity exceed 6 ft/sec.

The preliminary simulations were relatively ideal in that there was no time delay added in the ship position feedback into the controller. In practice there will be transport delay associated with transmitting or estimating the ship deck state. We ran simulations with a 0.2 sec time delay, and the sink rate results are shown in Figure 6 on the right. Performance was degraded slightly with only 37% of the cases where all three landing gear contacted at less than 2 ft/sec, but still no cases where relative velocity exceeded 6 ft/sec.

Landings were also evaluated at a higher gross weight (20,000 lbs) with mass moments of inertia scaled by the increase in weight (an 18% increase). The linear models in the control law were not modified (i.e. they still represented the 17,000 lbs helicopter). The control law performance degraded but only slightly. There were more cases where the lateral or vertical touchdown velocity of at least one landing gear did not meet the desired tolerance. In 53% of the cases, the green boundary (2 ft/sec) was exceeded, but in only one case (3.3%) was there a velocity outside of the blue boundary (but still within the red boundary). Power required was also recorded during these simulations. The maximum power observed was 2610 shp, which is well within the expected power limitations of a helicopter of this type. The results also demonstrate the robustness of the DI controller, since plant models and the controller design were not updated to reflect the higher weight and inertias.

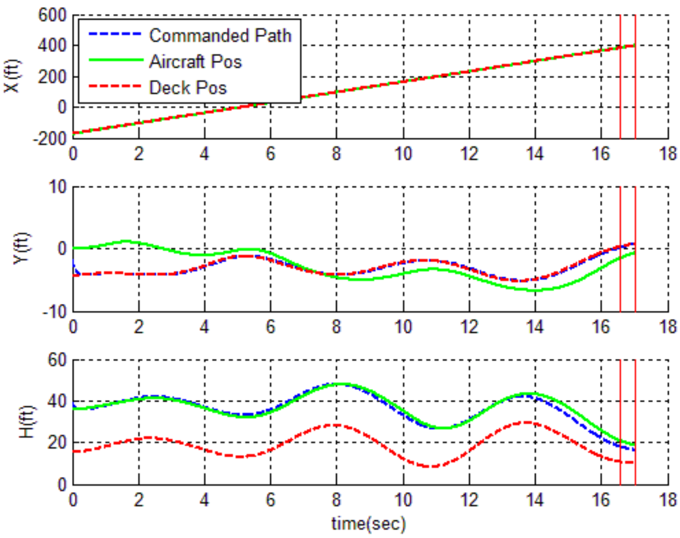
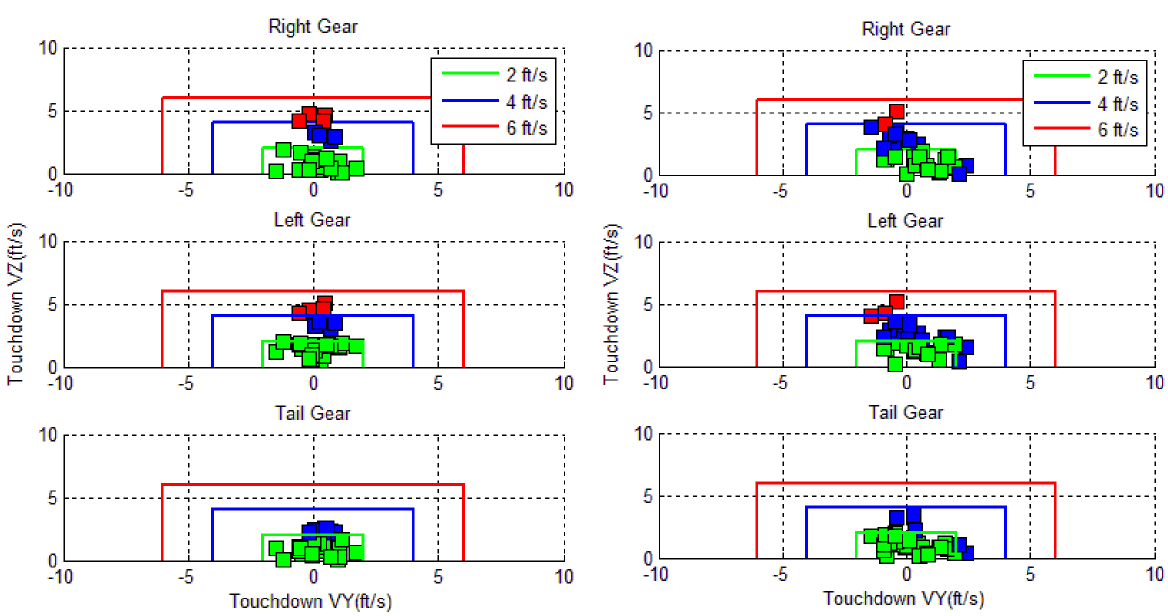


Figure 5 Sample landing trajectory



No Time Delay 200 ms Time Delay

Figure 6 Landing velocity scatter, 0.2 sec time delay

The second approach to landing integrates a classical optimal rendez-vous control law integrated with the deck motion prediction algorithms developed under Task 5. Optimal control theory methods are used to plan a descent path to the center of the landing deck such that the final vertical and lateral velocities match that of the deck at the expected touchdown time. This work was performed for the European Rotorcraft Forum paper submitted in July. This effort is being performed ahead of schedule, as integration of deck motion prediction with control was originally planned as a year 2 task.

The same outer-loop guidance control laws are used, but the commanded lateral and vertical positions and velocities (in the ship heading frame) are generated by the optimal control law. The x position and velocity in the ship heading frame still track the current deck position as in the previous method.

The optimal control scheme is based on the simple dynamics of a 1 DOF inertial system:

(1) $$\begin{aligned} \dot{y} &= v \\ \dot{v} &= a(t) \end{aligned}$$

This is a second order system with states y and v (position and velocity), and the control input a (acceleration). Note that the DI method effectively de-couples the four control axes, and the outer loop control scheme is well-suited to follow acceleration commands. Thus, Eq. (1) is a reasonable model for the lateral, longitudinal, or vertical outer loop commands, where a is the feed-forward acceleration command, v is the commanded velocity, and y is the commanded position.

We then seek a control law for $a(t)$ that takes the helicopter from current state $y(t_0)$ and $v(t_0)$ to a terminal state at a fixed time horizon $y(t_f)$ and $v(t_f)$. The time t_f is the prediction horizon of the deck motion prediction algorithm and the time to land. The terminal states are set to match the predicted deck state at the landing time. During the landing maneuver, the prediction horizon is shortened and the predicted deck state updated. The control law is derived from the classical optimal control problem that minimizes the following objective function, as seen in the optimal control text by Bryson and Ho:

(2) $$J = \tfrac{1}{2}c_1\left[v(t_f) - v_d\right]^2 + \tfrac{1}{2}c_2\left[y(t_f) - y_d\right]^2 + \tfrac{1}{2}\int_t^{t_f} a^2 dt$$

where v_d and y_d are set to match the forecasted deck state at touchdown. Thus the objective function minimizes a weighted function of terminal error and integrated control effort. In the case of vertical velocity, we add a negative bias to the terminal velocity of -1.5 ft/sec, to ensure that the helicopter descends down to wheel contact (rather than hover just over the deck).

The resulting control law is of the form:

(3) $$a(t) = -\Lambda_v(t)\left[v(t) - v_d\right] - \Lambda_y(t)\left[y(t) - y_d\right]$$

where Λ_v and Λ_y are time-varying gains defined in Bryson and Ho. The velocity and position weighting factors selected were, $c_1 = c_2 = 5$. This control law yields a commanded acceleration for both the lateral and vertical axes. The acceleration is integrated twice to yield commanded velocity and positions that are fed to the outer loop guidance law.

In order to avoid infeasible landing trajectories, the landing profile (in terms of accelerations, velocities, and positions) is calculated before initiating the landing sequence. The commanded accelerations and velocities must be within the following tolerances before initiating the landing:

(4)
$$\begin{aligned} &\left|a_y(t)\right| \le 0.2g,\ \left|a_z(t)\right| \le 0.3g \\ &\left|v_y(t)\right| \le 4 \text{ ft/sec},\ \left|v_z(t)\right| \le 6 \text{ ft/sec} \end{aligned}$$

In addition, the altitude profile is checked against forecasted deck altitude to verify that it will not make early deck contact. Once these tolerances are satisfied, the five second landing sequence is initiated. The target landing position and speed are updated every 0.096 seconds based on the latest deck forecast data from the MCA algorithm.

Preliminary landing simulations were conducted using the optimal predictive landing method. Figure 7 shows a sample landing trajectory that was successful. The landing sequence was initiated at 11.3 seconds into the simulation. As seen in the figure, the helicopter is commanded to hold a stable inertial hove over the landing deck until the landing maneuver begins. It then performs a more direct descent rather than follow the deck motion. The figure shows the predicted deck motion as generated by the MCA algorithm as the magenta line. The curve is shifted forward in time by the prediction horizon, which is 5 seconds for most of the simulation. At about 16.3 seconds these values "bunch up", as the forecast time is shortened throughout the descent maneuver. There is some significant error in the deck motion prediction, notably in the *y* position. But as the forecast time decreases, the prediction becomes more accurate, as shown by the magenta prediction line moving closer to the actual deck position shown by the red line.

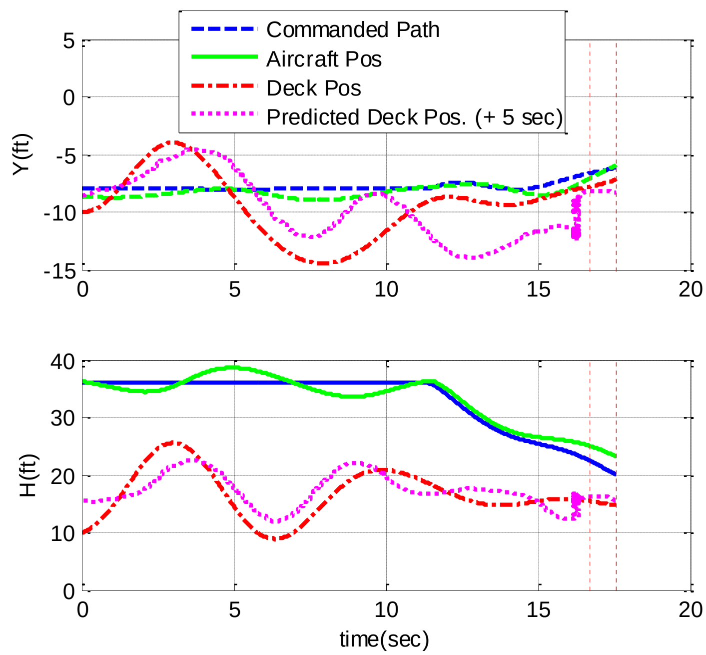


Figure 7 Sample landing trajectory with optimal predictive landing control law

For this case, the final x, y errors at touchdown were within the desired tolerances (0.9 ft, and 1.2 ft respectively). The vertical touchdown velocities of the front landing gear were slightly higher than desired (2.4 ft/sec) while the lateral velocity relative to the deck was only 0.3 ft/sec. While this particular case was relatively successful, the optimal predictive landing method has generally been found to perform less consistently than the simple landing method described in 5.1. In certain cases, phase errors in the heave motion prediction cause the helicopter to make deck contact too early, resulting in hard landings with sink rates as high as 10 ft/sec. Development and improvement of the control and prediction algorithm is ongoing. Based on preliminary results, it appears this controller is sensitive to inaccuracy in the forecasting algorithm.

Task 5 – Deck Motion Prediction Algorithm

During this reporting period, the MCA deck motion prediction algorithm (which was discussed in detail last reporting period) was fully integrated with the FLIGHTLAB simulation model. The prediction horizon of the algorithm is nominally set to 5 seconds, but it can be adjusted in real time during flight. The expected strategy is to shorten the prediction horizon during the landing sequence to predict deck state at the expected touchdown time. The deck motion prediction algorithm was integrated with the optimal control law for landing as described above.

Task 6 - Path optimization of shipboard helicopter:

The path optimization methods were developed extensively during this reporting period, and the results are presented in detail in our AIAA Atmospherics Flight Mechanics Conference paper presented in June 2015. A brief summary of the method and results is presented here.

As discussed in earlier progress reports, the approach path is represented by four parameters. The parameters V_0 and r_{pd}, represent the asymptotic (i.e., initial) approach velocity and range at which the peak deceleration occurs, respectively, and thus define the temporal properties of the approach (i.e., how quickly the helicopter approaches and decelerates—these design variables are given by $\boldsymbol{X}_{\text{temp}} = [V_0 \;\; r_{pd}]$). The relative glide slope, γ_{app}, and relative approach azimuth, ψ_{app}, define the geometry of the path in the ship reference frame, and therefore define the spatial properties—these design variables are given by $\boldsymbol{X}_{\text{spatial}} = [\gamma_{app} \;\; \psi_{app}]$. These parameters are illustrated in the figure below. The control law was designed to track approach paths with this parameterization scheme, and numerous simulation cases were run in FLIGHTLAB with no ship motion (other than the ship following a steady speed and course at 20 knots) and with a turbulent airwake corresponding to 20 knots, 0 deg WOD.

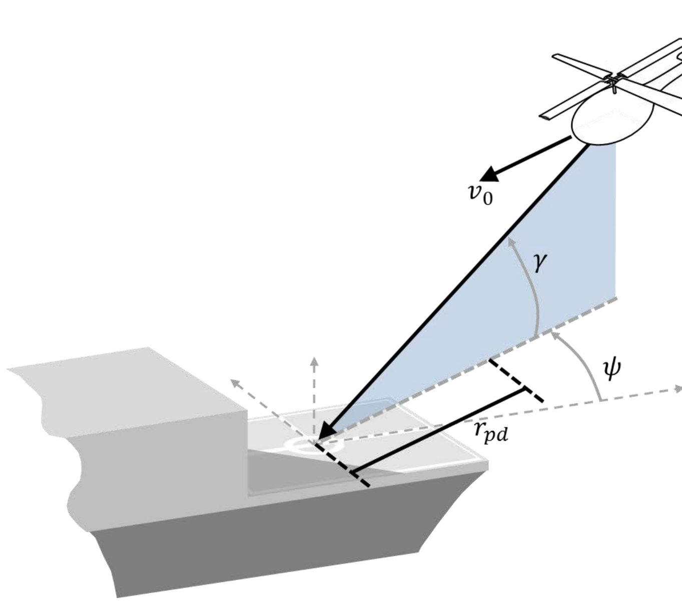


Figure 8: Approach Path Parameters

Two objective functions were designed to include multiple weighted performance factors, including transit time/power requirements:

$$W = \int_0^{t_{\text{end}}} P(t)\,\mathrm{d}t$$

Path error:

$$\varepsilon(t) = \sqrt{(x(t) - x_{\text{cmd}}(t))^2 + (y(t) - y_{\text{cmd}}(t))^2 + (h(t) - h_{\text{cmd}}(t))^2}$$

Airwake effects (as represented by thrust fluctuations):

$$\Delta T(t) = T(t) - \bar{T}(t)$$

The three performance factors can then be combined into a single cost function using various weighting schemes:

$$F(\boldsymbol{X}) = w_1 k_1(\boldsymbol{X}) + w_2 k_2(\boldsymbol{X}) + \ldots + w_n k_n(\boldsymbol{X})$$

In addition, constraint functions were considered to ensure operationally feasible/safe results:

Max pitch angle < 15 deg

Min height above deck > 10 ft

The optimization study involved 45 simulated approach profiles generated in 4 separate batches, after which the objective functions showed near-convergence. Initially 9 baseline and sensitivity cases were defined as shown in Table 2. These define the baseline case, X_1, as well as 8 perturbations which are used to evaluate gradients in the objective function. These cases were then run in FLIGHTLAB. The objective and constraint functions were evaluated, and an optimal was estimated and new perturbation cases defined. This process was iterated three times, resulting in the 45 cases.

Design number	v_0 (ft/sec)	r_{pd} (ft)	γ (deg)	ψ (deg)
$\boldsymbol{X}_1$	125	300	8	0
$\boldsymbol{X}_2$	125	300	**1**	0
$\boldsymbol{X}_3$	125	300	**15**	0
$\boldsymbol{X}_4$	**100**	300	8	0
$\boldsymbol{X}_5$	**150**	300	8	0
$\boldsymbol{X}_6$	125	**190**	8	0
$\boldsymbol{X}_7$	125	**500**	8	0
$\boldsymbol{X}_8$	125	300	8	**-45**
$\boldsymbol{X}_9$	125	300	8	**45**

Table 2 Baseline Sensitivity Cases

Four-dimensional results were analyzed using sets of contour maps, where $F(\boldsymbol{X}_{\text{temp}})$ are shown in a given contour map and $F(\boldsymbol{X}_{\text{spatial}})$ are shown across contour maps, as shown in Figure 9. The results show that the objective functions tend to be non-linear and highly non-convex. Results also indicated that the objective functions and constraints tended to be very sensitive to the temporal parameters, but mostly insensitive to the spatial parameters. The approach velocity and deceleration parameters govern the speed and aggressiveness of the approach, and one can analyze the tradeoffs of reduced time versus the degradation in tracking and higher power for an aggressive approach. On the other hand, at least for the symmetric 0 deg WOD conditions, the azimuth and glideslope have little impact. Future studies will examine skewed airwake conditions to see if spatial approach parameters play more of a roll. In addition, deck motion can also be considered.

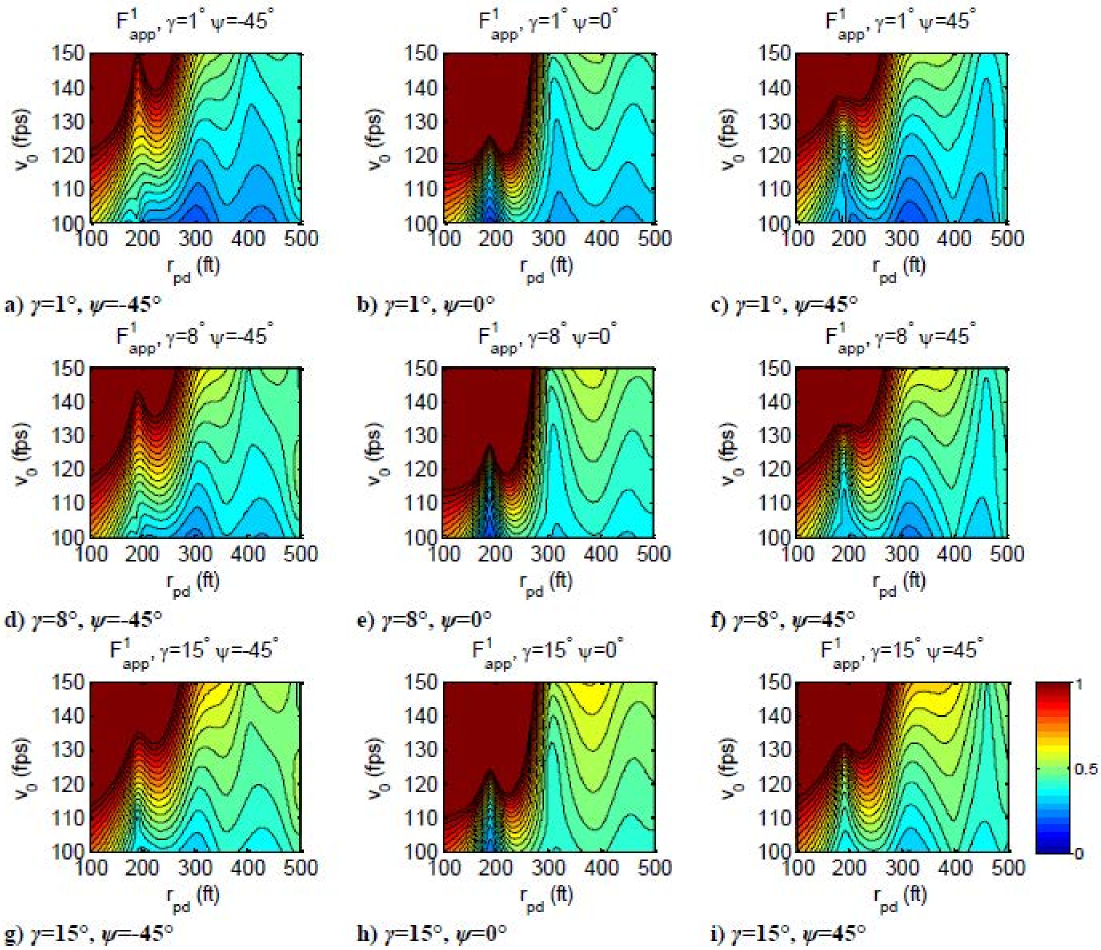


Figure 9 Sensitivity Analysis of Objective

3. Significance of Results

SCONE ship motion data are now integrated with the FLIGHTLAB models, allowing the research to make use of standardized ship motion cases. In addition, the MCA deck motion prediction algorithms were fully integrated with FLIGHTLAB. Both of these were major technical / code implementation tasks completed this reporting period.

The dynamic inversion control law shows very good performance in tracking deck motion, even for the medium amplitude SCONE case, which represents conditions not currently within the envelope of the H-60. Autonomous ship landing simulations using a simple deck tracking approach showed consistently acceptable performance. We should continue to add additional non-ideal effects (noise, time delays, off-nominal aircraft properties) to assess robustness of the control law.

Preliminary simulation of autonomous landing using deck motion prediction and an optimal control scheme are promising, but require further refinement.

The path optimization study demonstrated a methodology for formulating objective functions that may be incorporated in formal optimization studies for determining path guidance for autonomous shipboard recovery. The results of the study show that it is possible to generate objective functions that include multiple weighted

performance factors, but the weighting factors must be carefully selected to maintain a suitable balance between multiple performance factors that may oppose each other. Additionally, results indicate that the mathematical properties of the resulting optimization problem are dependent on the specific performance factors included in the objective function as well as their relative weights. This dependency may have implications on the tractability of trajectory optimization studies with certain objective function formulations. Although the optimization method produced improvements in the objective functions and was terminated because successive steps resulted in no appreciable improvement, the mathematical properties of the objective functions may have proven problematic if more stringent termination criteria were applied.

4. Plans and upcoming events for next reporting period

Plant Model and Disturbance Models: The distribution of the FireScout and heavy weight (H-53 class) FLIGHTLAB flight dynamics models was delayed due to efforts to integrate the SCONE ship motion data and to implement the MCA deck motion prediction in FLIGHTLAB. Development and distribution of these models is expected to be accomplished next quarter. Additional ship motion cases will also be implemented. We also plan to develop some addition airwake cases (based on the SFS2 generic frigate shape) with winds from port and starboard.

Control Law Development: As we move to year 2 of the program we will be initiating Task 8 *Station Keeping Control Laws* and Task 9 *Vertical Axis Control Laws*. These will be of course integrated with the DI control laws under Task 3 and 4. These tasks have essentially already started in this past reporting period. We will continue to develop novel control schemes for the station-keeping and landing phase, building on the optimal control method with deck motion prediction as presented in the ERF paper. For the vertical axis, we will bring in the issues of torque and control margin limits for the helicopter operating at high gross weights. ART will integrate the control laws as developed thus far for the generic medium weight class helicopter to provide our research team a consistent and unified model and analysis utilities to expedite further development. Configuration control is a challenge given the numerous members of the team at PSU, ART, NAVAIR, and NSWCCD.

Deck Motion Prediction: The MCA based ship motion forecast scheme has predicted the deck motion with reasonable accuracy, in fact, quite good in the variation trend. But, the forecasting accuracy of the motion peak amplitude needs improvement. We will investigate the algorithm implementation to explore any potential improvement. ART will also process and integrate more SCONE ship motion data with the simulation model for further test and evaluation.

Path Optimization: In the recent path optimization study, the thrust fluctuations caused by the turbulent ship airwake were the primary driver of the objective function characteristics. This relationship was a result of the relative weighting between performance factors and the normalization factors that were applied to each performance factor. In the upcoming quarter, work will focus on extending the initial study by examining alternate objective function formulations. Particularly, we will investigate the inclusion of additional performance metrics (i.e., actuator margins) as well as varied weightings between the performance factors.

5. References

Bryson Jr., A. E., and Ho, Y.C., *Applied Optimal Control: Optimization, Estimation, and Control*, Revised Printing, Hemisphere Publishing, Washington, D.C., 1975, pp.154-155.

6. Transitions/Impact

We continue to transition our models and control laws to counterparts at NAVAIR and NSWCCD (Sean Roark and Al Schwarz), and to John Tritschler (now at USNTPS).

A briefing was presented to Dave Findlay, Colin Wilkinson, and Eric O'Neill at NAVAIR in May 2015.

7. Collaborations

Penn State and ART have collaborated directly with John Tritschler and Sean Roark at NAVAIR. In addition, we are communicating with other Navy researchers pursuing similar projects: Al Schwarz at NSWCCD and Dave Findlay at NAVAIR.

8. Personnel supported

Principal investigator: Joseph F. Horn

Graduate Students: Junfeng Yang, PhD Candidate

9. Publications

Tritschler J.K., Horn J.F., and He, C. "Objective Function Development for Optimized Path Guidance for Rotorcraft Shipboard Recovery". AIAA Atmospheric Flight Mechanics Conference, Dallas TX, June 22-26 2015.

Final manuscript was submitted to the 2015 European Rotorcraft Forum in Munich Germany, September 1-3, 2015: Horn J.F., Yang, J.F., He, C., Lee, D., and Tritschler, J.K. "Autonomous Ship Approach and Landing using a Dynamic Inversion Control with Deck Motion Prediction."

10. Point of Contact in Navy

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11. Acknowledgement/Disclaimer

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Section II: Project Metrics

Contract # N00014-14-C-0004

Autonomous Control Modes and Optimized Path Guidance for Shipboard Landing in High Sea States

Progress Report (CDRL A001)

Progress Report for Period: April 10, 2015 to July 9, 2014

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Penn State University	U.S. Naval Test Pilot School	Advanced Rotorcraft Technologies

July 30, 2015

1. Metrics

Number of faculty supported under this project during this reporting period: 1

Number of post-doctoral researchers supported under this project during this period: 0

Number of graduate students supported under this project during this reporting period: 1

Number of undergraduate students supported under this project during this period: 0

Number of refereed publications during this reporting period for which at least 1/3 of the work was done under this effort: 0

Number of publications (all) during this reporting period:1

Number of patents during this reporting period: 0

Number of M.S. students graduated during this reporting period: 0

Number of Ph.D. students graduated during this reporting period: 0

Awards received during this reporting period: 0

Invited talks given: 0

Conferences at which presentations were given (not including invited talks above): 1